Proposal For:

Renewable Energies Based Hydrogen Production

Proposed To:

Dr. Thomas L. Acker
Associate Professor of Mechanical Engineering
Northern Arizona University

H2 Generation:
Josh Spear; Team Leader
Andrew Boone; Secretary
Ryan Hirschi; Financial Officer
Robert Burke; Team Mediator

Northern Arizona University
College of Engineering and Technology
ME 476 Capstone Design FA02

Last Revised: 12/3/02

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H2 Generation Contact Information:

Josh Spear; Team Leader (928) 853-1617, jds33@dana.ucc.nau.edu

Andrew Boone; Secretary (928) 523-3963, NAUBoone@yahoo.com

Ryan Hirschi; Financial Officer (928) 213-0007, rsh6@dana.ucc.nau.edu

Robert Burke; Team Mediator (928) 523-2876, rcb27@dana.ucc.nau.edu

Problem Definition:

The purpose of this project is to design a hydrogen gas production facility that uses the available water and renewable energy resources located behind the Northern Arizona University College of Engineering & Technology (CET) building.

Requirements:

The requirements of this project include the following:

- Use of existing renewable energy as the energy supply to produce hydrogen gas.
- Hydrogen must be stored in a manner available to properly fuel a hydrogen racecar.
- Use available rainwater (utilizing available rooftops) supplemented, if necessary, with CET tap water.

State-of-the-Art:

The state-of-the-art research conducted by H2 Generation consisted of three major areas including: hydrogen generation techniques, hydrogen storage techniques, and modern renewable energy based hydrogen production facilities.

- Firstly, the methods of *producing hydrogen* that were researched included electrolysis of water (splitting water into hydrogen and oxygen), introduction of acids to scrap metals, and reforming methods (coal, CH_4). The major advantages of each method were examined for relative cost, availability and practicality in the university setting. After reviewing this information with the client water electrolysis was chosen. For a summary of all types of hydrogen production procedures and decision criteria see Appendix 1.

- Secondly, the methods of *storing hydrogen* that were researched included liquid hydrogen, compressed gaseous hydrogen, and metal hydrides. These methods were discussed with the client. Liquid hydrogen was discarded due to cost and complexity. The hydride and compressed gas storage methods were studied in detail and compressed gas was found to be the most appropriate alternative for the client. For a summary of the different hydrogen storage methods and decision criteria see Appendix 2.

- Finally, complete *renewable energy based hydrogen production facilities* were researched. The research revealed that there are such stations in existence, but they are not commonplace. An example of renewable based hydrogen production facility is in California and uses solar energy to power electrolysis. For more information on modern hydrogen generation systems see Appendix 3.

Proposed Solution:

H2 Generation proposes to provide two deliverables in the solution to the renewable energy based hydrogen production problem. The first deliverable will be the specification of the design layout for the production facility. The second deliverable will be to construct and test a proof of concept model.

1. The *first* deliverable, the full scale design, will incorporate the following five components:

- Reclaim/treatment of rain water
- Power generation
- Water electrolysis
- Hydrogen process/storage
- Data acquisition and control

Each of the above components will be individually designed as needed to complete the overall project design. Important aspects to be addressed concerning the entire design layout are as follows:

- Estimating maximum and minimum hydrogen production based on projected renewable energies and rainfall
- Thermodynamic analysis of each component and complete design layout
- Environmental and Safety analysis
- System maintenance analysis & plan
- Web page to be used for promotion of concept

2. The *second* deliverable will be a proof of concept model to demonstrate the viability of a full-scale prototype. The model will be completed for visual approval and design layout confirmation. The model will include but not limited to the following:

- Collection and filtration of water
- Battery simulating renewable energy powering electrolysis
- Hydrogen and oxygen production

Project Management:

The H2 Generation team has created a comprehensive schedule entailing deliverable dates and milestones aiming for the completion of the project (Appendix 4 Figure-1). Listed here is a summary of important dates.

The important dates remaining for the Fall 2002 semester include:

- Acceptance Documents 12/10/02

The important dates for the Spring 2003 semester include:

- Begin Preliminary Model Design 12/9/02
- Begin Preliminary Full Scale Design 1/13/03
- Preliminary Full Scale Design Deliverable 1/30/03
- Receive edited Preliminary Full Scale Design Deliverable 2/13/03
- Preliminary Model Design Deliverable 2/13/03
- Begin Refining Design 2/13/03
- Preliminary Model Design Complete Approval 2/20/03
- Model Delivered 4/21/03
- Finalized Design 4/21/03
- Capstone Conference 4/25/03
- Final Report Due 5/5/03

Over the fifteen-week design period, H2 Generation will accumulate approximately 48 hours per week resulting in 720 working hours for the project.

Costs:

H2 Generation has an estimated budget of $1000 for the completion of this project. All purchases are to be pre-approved by client.

The use of this budget shall go to the following purposes:

- Acquiring resource materials for use in design (books, software, etc.)
- Document construction (paper, copies, etc.)
- Model construction (electrolyzer, tubes, etc.)

Summary of Benefits:

H2 Generation is offering to complete the design and proof of concept model for a renewable energy based facility to produce hydrogen to fuel a formula-one racecar. Team qualifications and experiences includes:

- four years of hydrogen gas production research
- two years of web page designing
- successful interning in several varied applications
- H2 Generation's state-of-the-art research

Our two main deliverables are the Proof of Concept Model and the Final Report of the Design Layout; the benefits of which are seen in Table-1 below.

Table-1: Benefits

Benefits of Model	**Benefits of the Design Layout**
Proof of concept	Design will be construction ready
Educational demonstration tool	Environmental and safety factors already incorporated into design
Recruiting device	
Medium for increased awareness of the *Renewable Energy Center*	

Acceptance:

Northern Arizona University Capstone Design Team Members:

______________________________ __________

Joshua Spear Date

______________________________ __________

Robert Burke Date

______________________________ __________

Ryan Hirschi Date

______________________________ __________

Andrew Boone Date

Northern Arizona University College of Engineering and Technology, Renewable Energy Resource Center

______________________________ __________

Dr. Thomas Acker Date
Professor of Mechanical Engineering
College of Engineering and Technology
Northern Arizona University

Appendix 1: Hydrogen Production Processes and Evaluation

Introduction:

Hydrogen production can be initiated in many fashions, below are the most used and readily available technologies. The information given is a quick synopsis of varying types of hydrogen production and their benefits or drawbacks.

Electrolysis

What it is: Electrolysis is the process of producing hydrogen and oxygen from electricity and water (Peavey 2002).

How it works: Each water molecule (H_2O) has 2 hydrogen atoms (positive ions) and 1 oxygen atom (negative ion). In an electrolyzer, an electrical current is passed through water. The (positively charged) hydrogen atoms collect at the negative electrode and the (negatively charged) oxygen atoms collect at the positive electrode. Water is continually pumped into the electrolyzer while hydrogen and oxygen are continually pumped out, thus isolating hydrogen gas (Peavey 2002).

In order for less electricity to be used, the electrical resistance of water must be reduced. This is accomplished by; 1. Heating the water up to between 700 and 1000C. 2. Put a salt like sodium chloride into the water. 3. Then place an acid such as sulfuric acid or a base such as potassium hydroxide into the water.
Thermal Efficiency = Energy in / Energy out = 30 to 35%
Voltage Efficiency = Minimum Voltage Needed / Actual Voltage = 1.24V / Actual Voltage DC = 65 to 75% (Peavey 2002).

Higher current flow results in greater efficiency. To maximize the current flow thin electrodes should be used because the current density on them is higher(Peavey 2002).

A homemade electrolyzer is about 50% efficient. Conventional electrolyzers operate at 75 to 80C. At this temperature, the required input energy is 4.8 kWh per cubic meter of hydrogen produced (Peavey 2002).

A high-pressure electrolyzer operates at 200C and 10MPa and is about 75% efficient. A Solid Polymer Electrolyzer is the most efficient to date. It uses a solid instead of a liquid as the electrolyzer. It operates at between 120 and 150C and is up to 85% efficient (Peavey 2002).

<u>Fuel From Carbon</u>

Hydrogen from Steam and Coal

Hydrogen can be produced many ways: petroleum reforming – 77% of world hydrogen production; coal gasification – 18% of world hydrogen production; and electrolysis – 4% of world hydrogen production. Coal gasification is becoming cheaper with increased technology and research (Peavey 2002).

Steam Reforming of Coal:

Hydrogen is produced by using steam to reform most carbon-containing materials (coal). The reaction of carbon with steam producing hydrogen is:

$$\text{Heat} + C + H_2O \rightarrow CO + H_2$$

This is an endothermic reaction, and the higher the temperature of the steam reforming the more hydrogen produced.

Thermodynamic Cost of Hydrogen Production:

Hydrogen is produced by coal first by producing synthesis gas and then reacting the carbon monoxide with steam. In an ideal process, the energy amount in the hydrogen is equal to the original energy amount in the carbon. 82.8% of the energy available in the carbon is used when hydrogen is burned. The thermodynamic penalty to convert synthesis gas into hydrogen is relatively small; there are several advantages to the extra steps of gas conversion (Peavey 2002):

1. hydrogen may be transported by pipeline over greater distances
2. hydrogen burns cleanly
3. hydrogen may be substituted for other fuels usually with minor changes

The disadvantage will be the use and exposure of possible toxic gases produced by the liberation of hydrogen using coal gasification (Peavey 2002).

Summary

The coal gasification method will call for high amounts of heat for the steam reforming process. An advantage to this method is the adaptability to environmental cleanliness, but at the same time could have a discharge of carbon dioxides and carbon monoxide. Hydrogen is produced in the same manor methane is, just one step further of reacting the carbon based gas with steam for hydrogen. The liberation of hydrogen by means of coal gasification is at the maximum of today's technology, at 82.8% efficiency.

<u>Introduction of Acids to Scrap Metal:</u>

This process uses chemical reactions of substances including hydrides to produce hydrogen gas.

Hydride: A compound of hydrogen with another, more electropositive element or group. (http://www.bartleby.com/61/27/H0342700.html)

Advantages of chemical system (Peavey 2002):

- In certain reactions only H2 gas is produced making gas separation unnecessary and storage simpler and safer
- Ability to recycle old metals such as iron, to obtain fuel

Disadvantages of chemical system (Peavey 2002):

- Supply of chemicals: Acid, Metal
- Using resources which are not unlimited (iron, aluminum, etc.)
- Discarding and recycling of used chemicals

Mobility possibilities of chemical system:

An abstract taken from: http://www.delphion.com, which describes a portable hydrogen generation system that uses hydrides to release hydrogen gas.

Feasibility of chemical system:

"The use of this type of system under the guidelines of this project is not advisable. The project at hand is supposed to focus on renewable energy sources, such as photovoltaic or wind produced electricity. Instead the use of a chemical system would involve obtaining the needed chemicals and metals, then causing a reaction that will ultimately transform these materials into hydrogen gas and some other product. At this time more materials would need to be obtained. In this was the project would need a fair amount of continuous funding, and maintenance."

Example of chemical system in use:

A hydrogen generator employs substantially adiabatic hydrolysis and thermal decomposition of chemical hydrides to provide a controllable generation of hydrogen from a small, lightweight container. The hydrogen generator includes a thermally isolated container for containing a chemical hydride, a preheater to heat the chemical hydride to a predetermined temperature before the chemical hydride is hydrolyzed, a water supply controlled to maintain substantially adiabatic and controlled generation of hydrogen from said chemical hydride, and a buffer to supply an initial flow of hydrogen during generator start-up, absorb excess hydrogen during generator shut-down, and to smooth the hydrogen flow due to changing loads.

Sheridan Ross PC 2002

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Peavey, Micheal A. "Fuel From Water: Energy Independence with Hydrogen." Tenth Edition, New York: Merit Inc. 2002.

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Appendix 2-A: Hydrogen Storage Methods

The three types of hydrogen storage are in a gaseous, liquid, or solid state. Each type of storage has distinct advantages and disadvantages.

Gaseous Hydrogen:

The container for hydrogen storage must be made of strong lightweight material. This material must also be able to resist embrittlement effects due to the pressure inside the tank. Due to the size of the hydrogen atom it are forced, with high pressure, in between, the molecules of the metal compound in the tank walls and weaken the bonds for the metal. The containers must be able to contain the gas without leaking for risk of explosion (Peavey 2002).

Pro: The use of gaseous hydrogen is usually preferred due to its easy containment. Most hydrogen produced is already in a gaseous state (Peavey 2002).

Con: The use of gaseous hydrogen becomes a problem because of its low energy to volume ratio of 300 watts/liter. To acquire the same proportional mileage in a car the volume of hydrogen stored on the car has to be three times the size of the original gas tank, with gasoline having a energy to volume ratio of 8890 watts/ litter. The weight of a tank to hold the hydrogen becomes cumbersome and extremely heavy (Peavey 2002).

Liquid Hydrogen:

Pro: The energy per volume becomes 2398 watts/liter when it is stored as a liquid. This change in energy desity, from a gas to a liquid allows for smaller storage containers and equivalent energy per volume to that of gasoline (Peavey 2002).

Cons: Hydrogen in a liquid state must be stored at –253C, which leads to the consumption of energy that the cooling unit for storage will use, is around 30% of the total energy stored in the tank. Storage containers must be highly insulated, which leads to high costs. Near absolute zero many metals are brittle and shatter like glass, so specially designed pumps are used to supply the engine with fuel (Peavey 2002).

Hydrides:

Gaseous hydrogen may be stored inside certain metals called hydrides. The metal absorbs the hydrogen gas at high pressure and low temperature. Heat and low pressure are applied to release the hydrogen from the metal. The mass of hydrogen atoms follow the heat flow into and out of the metal, charging and discharging the gas as conditions dictate (Peavey 2002).

Pros: Storing hydrogen as a hydride is the safest means and it contains the highest volume and weight for stored hydrogen. This storage medium contains 3254 watts/liter, which is the heist of all three mediums (Peavey 2002).

Con: The mass energy density for the hydride is small compared to that of liquid or gaseous hydrogen. Some issues that come from using hydrides are the cost of the material, and its dissociation temperature (Peavey 2002).

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Appendix 2-B: Storing Compressed Hydrogen Gas for Use as a Fuel

Cost Issues:

The cost for storing gas is high due to tanks being material intensive to handle high pressures. As our research has shown, these high pressures are necessary to travel any fair distance in a motor vehicle.

- Using compressed gas hydrogen costs approximately 4 times gasoline cost. This source also claims a much higher cost for using hydrides (MIT elab 2002).

- **H2 Tank**: 41 liters @4000 psig $135 + Regulator $314 => 0-140F (FuelCellStore.com 2002).

- **H2 Tank**: 330 liters @ 4000 psig $279 + Regulator $314 => 0-140F (FuelCellStore.com 2002).

Many sources have claimed that natural gas storage tanks can be used also (SEE Maintenance of Hydrogen Cylinders.)

Maintenance of Hydrogen Cylinders:

- Hydrogen compressed gas tanks must be periodically inspected and tested.
- Hydrogen-Tight test upon installation.
- If out of service 1 year, must be inspected and safety relief devices checked.
- Steel and other iron compounds can become brittle due to hydridization.
    - Nickel compounds prevent this
    - Aluminum lining
    - Generally compressed gas tanks designed for other gasses can be used

    Example: German pipeline using natural gas pipe since 1940 with no signs of embrittlement yet (Peavey 2002).

Feasibility of Storing Compressed Hydrogen An (OSHA 2002):

Basic guidelines for installation of storage units:

- Must post warning signs
- Area near unit must be kept clean
- Stored in a safe place (proximity to people, heat sources, etc.).
- Ventilation if indoors is required
- Easily and safely moved with cart

References

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OSHA. “OSHA Answers.” http://www.ccohs.ca/oshanswers/safety_haz/welding/storage.html Last viewed:12/3/2002

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Appendix 3: Plant Hydrogen Production

Schatz Hydrogen Project

The Schatz solar hydrogen project is a full-time, automated standalone energy system designed to power an air compressor for marine enviornments. This system incluces the use of electrolizers, solar cells, and compressed storage of hydrogen (Marshall 2002).

The system specifications are as follows:

- A 7 kW (actual max output) photovoltaic array (192 M75 Siemens modules)
- A 7 kW electrolyzer producing 20 standard liters of hydrogen per minute (max)
- Three 500 gallon tanks for hydrogen storage at 100 psi
- A 1.5 kW proton exchange membrane fuel cell
- A computer control system, preforming automated control and monitoring

HyGen Industries

HyGen industries, is a company focused on the creation of a hydrogen infrastructure. There services include:

- Car conversions from gasoline to hydrogen fuel
- Hydrogen production through solar cells and electrolysis
- Hydrogen production through methane reforming
- Consultation for new production facilities

The focus for this company is the expansion and development of hydrogen fleets. There intent is to create the hydrogen revolution in California while continuously expanding (HyGen Industries, LLC 2002).

References

Marshall, Marc. "The Schatz Solar Hydrogen Project." http://www.humboldt.edu/~serc/trinidad.html Last edited: 07/31/2002 Last viewed: 12/03/2002.

HyGen Industries, LLC. "Hydrogen Energy Products." http://www.hygen.com/products_services.htm Last viewed:11/30/2002.

Appendix 4: Hydrogen Production Team Schedule Spring 2003

Appendix 5: Overall Reference List

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